

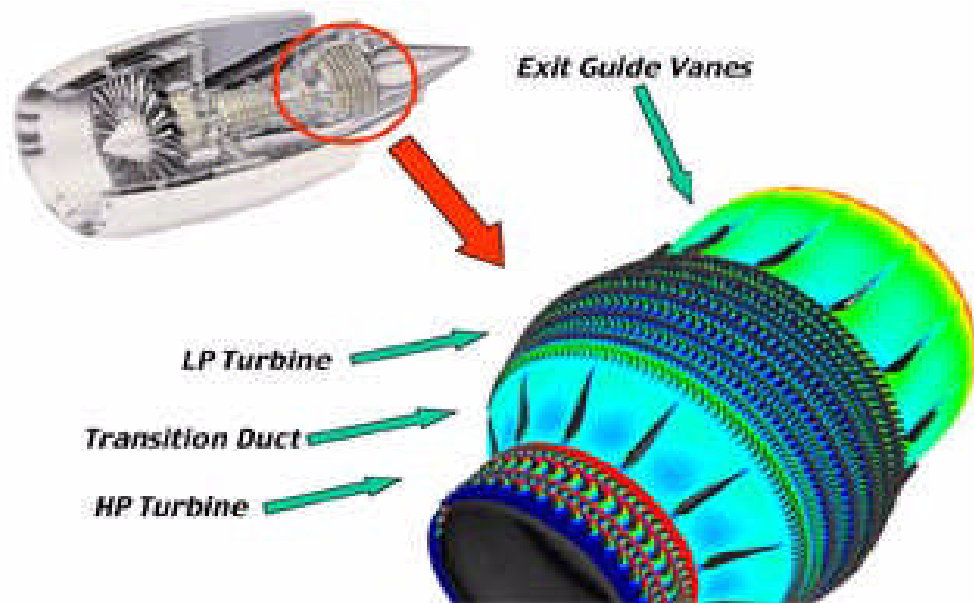
# **Coupled-Flow Simulation of HP-LP Turbines Has Resulted in Significant Fuel Savings**

Our objective was to create a high-fidelity Navier-Stokes computer simulation of the flow through the turbines of a modern high-bypass-ratio turbofan engine. The simulation would have to capture the aerodynamic interactions between closely coupled high- and low-pressure turbines.

A computer simulation of the flow in the GE90 turbofan engine's high-pressure (HP) and low-pressure (LP) turbines was created at GE Aircraft Engines under contract with the NASA Glenn Research Center. The three-dimensional steady-state computer simulation was performed using Glenn's average-passage approach named APNASA. The areas upstream and downstream of each blade row mutually interact with each other during engine operation. The embedded blade row operating conditions are modeled since the average passage equations in APNASA actively include the effects of the adjacent blade rows. The turbine airfoils, platforms, and casing are actively cooled by compressor bleed air. Hot gas leaks around the tips of rotors through labyrinth seals. The flow exiting the high work HP turbines is partially transonic and, therefore, has a strong shock system in the transition region.

The simulation was done using 121 processors of a Silicon Graphics Origin 2000 (NAS O2K) cluster at the NASA Ames Research Center, with a parallel efficiency of 87 percent in 15 hr. The typical average-passage analysis mesh size per blade row was 280 by 45 by 55, or ~700,000 grid points. The total number of blade rows was 18 for a combined HP and LP turbine system including the struts in the transition duct and exit guide vane, which contain 12.6 million grid points. Design cycle turnaround time requirements ran typically from 24 to 48 hr of wall clock time. The number of iterations for convergence was 10,000 at  $8.03 \times 10^{-5}$  sec/iteration/grid point (NAS O2K). Parallel processing by up to 40 processors is required to meet the design cycle time constraints.

This is the first-ever flow simulation of an HP and LP turbine. In addition, it includes the struts in the transition duct and exit guide vanes.



*Modern high-bypass-ratio turbofan engine with closely coupled high- and low-pressure turbines.*

The flow simulation of the closely coupled HP and LP turbines resulted in efficiency predictions that fall within 0.8 and 0.5 percent of data taken on component test rigs, and shock interaction loss was predicted within 0.5 percent. Analysis of the simulation has identified excessive turbine aerodynamic interaction losses that can be reduced by 50 percent. The reduction in turbine interaction losses will result in a \$3 million/year savings in fuel costs for a fleet of aircraft. The high parallel efficiency and accurate simulation now make APNASA practical to use in the design environment. This work is a major element of the Numerical Propulsion System Simulation (NPSS), and it supports the High Performance Computing and Communication Program Grand Challenge milestone: "Demonstrate Impact of Improved Engine Simulation Capability."

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